

Nexleaf Analytics

Strengthening Climate Resilience for Health Infrastructure: Lessons from the Cold Chain

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THE PROBLEM

The Cost of Ignoring Maintenance



12-15%

of CCE is failing catastrophically



9.6

million children under 1 left unprotected



$382M

in vaccines + delivery cost likely lost potency due to cold chain failure annually

Cascading Impacts of Extreme Heat on Health Systems

From grid strain to vaccine loss: why real-time monitoring and maintenance are climate adaptation

Step 01
Heatwave Spikes

Extreme ambient temperature drives maximum cooling demand.

→

Step 02
Grid Strain & Battery Failure

Power grid fluctuates; unmonitored battery backup fails silently.

→

Step 03
Cooling Systems Fail

Fridges cycle out of safe range and ward cooling collapses.

→

Step 04
Health System Loss

Critical vaccines are destroyed and patients endure heat stress.

Heat Makes Everything Worse at Once

Power grids face peak strain precisely when health clinics need active cooling most. Failing battery banks frequently go unnoticed until temperatures breach safe cold-chain limits.

Sensors as a Climate Data Layer

Real-time indoor temperature and power tracking across thousands of facilities turn existing sensors into actionable intelligence. Combined with heat forecasts, ministries can dispatch technicians before failure occurs.

Maintenance IS Climate Adaptation

A climate-resilient health system is fundamentally a well-maintained one. Building new infrastructure is the easy part; ensuring operational continuity for 20+ years is real adaptation.

[1] McCord et al. (2026), *PNAS*. Power reliability (>22 hrs/day) at healthcare facilities is associated with a 40% reduction in mortality.

Why Maintenance is Critical to Climate Resilience

Quantifying the human and operational impacts of reliable health facility power

A recent PNAS study by McCord et al. (2026) demonstrates that maintaining **reliable power (>22 hours/day)** in health facilities directly drives health outcomes and workforce capacity:

230,000

Children at Risk / Year

Without preventive maintenance, equipment designed to last 20 years fails prematurely, threatening vaccine viability. In Tanzania alone, nearly 230,000 children per year face compromised vaccines.

40%

Decrease in Patient Mortality

Consistent electricity ensures essential medical devices, cold chain equipment, and emergency care functions without life-threatening interruptions.

24%

Increase in Staff-Days Worked

Reliable facility infrastructure significantly improves working conditions, operational productivity, and nursing workforce availability.

[1] McCord et al. (2026), *PNAS*. Study examining the impact of reliable power (>22 hours/day) in healthcare facilities.

Tanzania: Rural Electrification & The O&M Challenge

The Investment

US$850M+

Committed by Tanzania with World Bank financing through TREEP & ASCENT TZ.

3,000+

Health facilities targeted by programme close.

Expected Design Life: **20-25 Years**

The O&M Challenge

< 4 Years

Observed service life collapses without an active operations and maintenance regime[1].

1 in 3

Solar systems at African public health facilities are already non-functional[2].

[1] ScienceDirect (Energy for Sustainable Development), *Off-grid solar waste in sub-Saharan Africa*, 2022.
[2] World Economic Forum, *Renewable Energy for Healthcare in Sub-Saharan Africa Requires Innovative Financing*, 2022.

Tanzania: Remote Temperature Monitoring & Solar Alignment

Analyzing system reliability trajectories across overlapping health facilities

Facility Cohort

4,769
Remote temperature-monitoring devices deployed

2,185
MOH Solar Registry health facilities

1,569
Active Overlap Target Cohort
Facilities equipped with both RTMDs and solar power systems

Reliability Trajectory of Overlap Cohort (1,569 Facilities)

39.8%
Good Performance
< 1 outage/month or showing active improvement

43.4%
Concerning Performance
Degrading performance or >50% of months with outages

16.8%
Mixed/Variable Performance
Unstable metrics with no clear directional trend

Rapid Response and Repair (R3) Package of Solutions

Program Components


R3 Playbook


Rapid Response Fund


AI-Driven Learning & Enablement


Mainstream RTM Data Use


CCE Data Digitization

Country-Led Innovations

Malawi

Technician Mentorship & Supportive Supervision

Strengthening local capacity through direct field-level mentorship for cold chain technicians.

Rwanda

Learning & Enablement for CCE Maintenance

Designing dedicated, sustainable training paths and toolkits to scale up equipment maintenance.

Tanzania

Integrated CCE Module for MEIMIS Platform

Building digital workflows to integrate cold chain equipment inventory within the national MEIMIS system.

Outcomes


Increased CCE Uptime


Efficient, Accountable, & Transparent Data Systems


Safeguarded Vaccine Potency


Reduced Costs over CCE Lifecycle

Evidence & Insights: Highlights from the Data

Preventive Maintenance

Preventive maintenance (PM) is highly correlated with CCE functionality.

21x

More Likely to be Functional in Rwanda

Building PM is possible in a short time.

12% → 85%

PM Coverage Increase in Malawi



Data & Funding Access

In **Malawi**, facilities with both RTMD and RRF access achieved:

100%

CCE Functionality



$$

Country-level intervention: CCE Retrofit

Tanzania converted 11 absorption CCE to compression cooling using at a cost of ~$700 each, compared with $7,700 for a new unit.

$77,000

Saved via a Rapid Response Fund

Converting 2,449 outdated CCE costs $1.7 million versus $18.9 million to replace — **a savings of over 90% and over $17 million.**



The Foundation for a Successful Maintenance System

solar_power

Equipment, Spare Parts & Facility Power

laptop

Accessible Data

fact_check

Workflows & Processes

groups

Trained Staff

monetization_on

Funding for Operations

published_with_changes

Structured Performance Review

Continuous Accountability & Feedback Loop

COLD CHAIN MAINTENANCE SYSTEM FRAMEWORK

How reliable vaccine cold chain performance emerges across the equipment lifecycle through preventive and corrective maintenance.

Evidence ↓ Learning Strengthening

1. SYSTEM FOUNDATIONS

Governance & Accountability
- Policies and SOPs for maintenance and decommissioning.
- Roles, responsibilities, and escalation pathways.
- Supportive supervision and accountability.

Maintenance Financing
- Maintenance budgets.
- Emergency repair funds.
- Timely disbursement.
- Budget lines for O&M, spare parts, power, workforce, and data systems.

Equipment, Power and Spare Parts
- Equipment procurement and commissioning.
- Power continuity (grid and solar).
- Spare parts availability and stock management.

Workforce Capacity
- Technicians.
- Mentorship / training.
- Tools and job aids.
- Adequate coverage and retention.

Data & Digital Tools
- Equipment registry.
- RTM / data use.
- Data quality & integration.
- Connectivity and decision support.

2. OPERATIONAL WORKFLOWS

1. **Regular Data Review** — District & national performance reviewed routinely.
2. **Asset Tracking** — Every CCE is registered, located, and its status is known.
3. **Service Request & Reporting** — Issues are reported quickly and clearly.
4. **Warranty Claims** — Eligible repairs are claimed before funds are spent.
5. **Spare Parts Access** — Parts are available when and where needed.
6. **Funding Authorization** — Funds are released rapidly for action.
7. **Dispatch & Repair** — Technicians are dispatched and repairs completed.
8. **Verification & Testing** — Repair is verified and equipment is tested.
9. **Resolution, Closure & Documentation** — Data is captured, records updated, and lessons reported.

3. CCE LIFECYCLE & MAINTENANCE OPERATIONS

Procurement & Installation → Preventive Maintenance → Corrective Maintenance → Replacement & Decommissioning

Incidents reveal system gaps

4. COLD CHAIN PERFORMANCE

1. Maintenance Performance
- Response Time
- Issue Resolution
- Preventive Maintenance Coverage

2. Equipment Performance
- CCE Functionality
- Uptime
- Temperature Stability

3. Service Protection
- Temperature Excursion Risk
- Vaccine Potency Risk
- Service Continuity

5. CONTINUOUS IMPROVEMENT & SYSTEM LEARNING

- Review recurring failures
- Update SOPs and job aids
- Improve spare parts planning
- Strengthen supervision and financing
- Plan replacement of obsolete equipment

Evidence from maintenance strengthens planning, operations, and investment.